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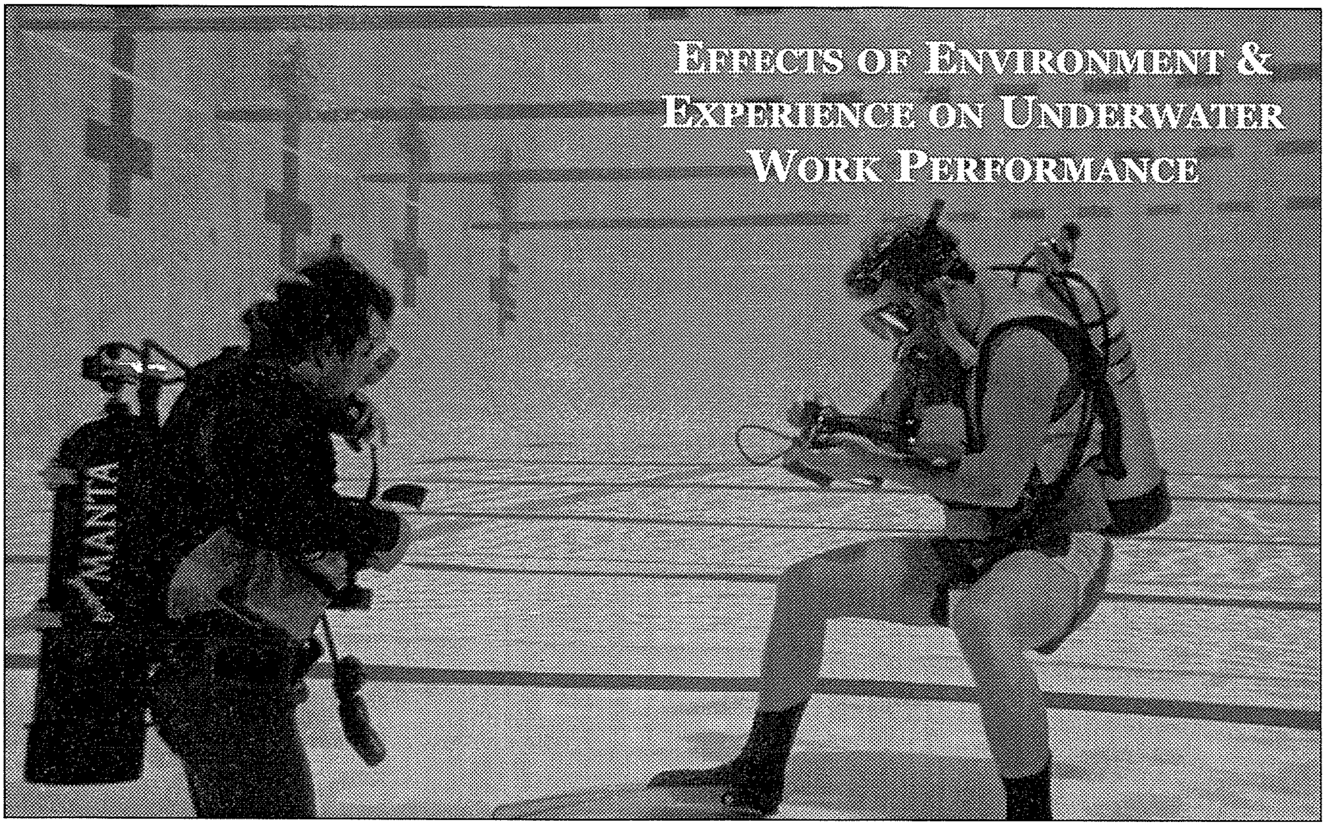

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ABSTRACT

Five experienced divers and 15 novice divers completed a complex underwater assembly task and sets of written problems in a water-filled tank and in the ocean. Performance measurements included subtask completion times, problem-solving accuracy, activity analysis, and basic physiological variables. Experienced divers showed essentially unchanged performance between tank and ocean. Notice divers performed slower than the experienced divers in the tank and showed a marked decrement in both assembly time and problem-solving accuracy in the ocean. The results suggest that diving experience improves underwater motor skills rather than work strategy, and that psychological stress was a significant factor even at shallow ocean depths for novices.

INTRODUCTION

The working diver is called upon to demonstrate a wide variety of skills. In accomplishing a typical underwater job, the diver's motor activities range from fine manipulation to man-handling of heavy weights. Body location and orientation change constantly. Submerged objects and tools must be located and identified. Problems imposed by the task and environment must be recognized and solved. Finally, the diver must coordinate his actions with his partner and with a topside station, generally without adequate communication facilities.

Controlled study of such diversified performance poses considerable difficulties. Several recent publications have described the development and use of diving test batteries composed of a number of separate measurements, which relate to specific activities or skills (Baddeley, Figueredo, Hawkswell Curtis, and Williams, 1968; Reilly and Cameron, 1968; Bowen, 1968). Studies adopting this approach are of great value in clarifying the specific effects of underwater environments, but it is frequently difficult to integrate their results to form a picture of performance on "real" underwater jobs.

At UCLA, underwater performance research has emphasized the use of comprehensive task simulations which incorporate virtually the full range of diving skills. Interest is in work measurement methodology, as well as in diver performance itself. Accordingly, this approach has had the advantage of providing a framework within which field measurement techniques can be developed, and of yielding data on divers closely related to real-life performance. The first research steps were undertaken in 1967, when a simulated construction task was developed along with a methodology for procedural and physiological underwater work measurement. (Weltman, Egstrom, Elliott, and Stevenson, 1968).

The purpose of the present study was to examine the effect of tank and open-ocean environments, and of varying amounts of diving experience on construction-task performance. It is reasonable that studies of underwater performance should involve highly experienced divers working in an ocean locale, because this most closely, resembles the real-world situation. But such studies are far more costly than laboratory observations made with the generally less experienced diving subjects. One problem, therefore, was to determine the extent to which the two situations could be equated; that is, whether empirically derived correction factors might feasi-

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bly be used to relate performance in one environment to performance in the other. In addition, another problem was to determine, if possible, what aspects of underwater performance are most sensitive to variations in environment and diving capability, so that subsequent measurement techniques might be developed to focus on them. Observations were restricted to shallow depths to avoid the effects of nitrogen narcosis, and to maintain a reasonably safe experiment for the inexperienced subject group.

METHOD

Simulated Task

The simulated diving task consisted of the assembly, pressure test, and disassembly of a bolted pipe structure (shown in Figure 1 with its associated pressure-test console). The pipe structure was fabricated of 2-in. galvanized pipe and correspondingly sized flanges, elbows, non-functional valves, etc. It was about 7 ft. high on a 4 X 5 ft. base. The pressure test console contained a bottled air supply, attached through a gate valve and flexible hose to the valve manifold on the pipe structure. A pressure gauge on the console displayed the hose pressure in psi above atmospheric pressure. Loose plastic sheets of instructions and diagrams for pipe structure assembly were secured to the pressure test console, along with two sets of written problems.

Assembly. Three main sections of pipe and the valve manifold (shown shaded in Figure 1) were bolted together using 1/2-in. nuts and bolts and a specified combination of open and solid gaskets. The pipe sections weighed 39, 44, and 50 lb., respectively, and generally required both team members to place and secure them. The bolts were tightened using an adjustable wrench and a torque wrench. A torque of about 40 ft.-lb. was necessary to insure an adequate seal during subsequent pressure testing.

Pressure test. The assembled portion of the pipe structure was cleared of water, pressurized, and checked for leaks. Each section leading from the valve manifold was tested independently. The test consisted of opening the appropriate test and vent valves, introducing air from the test console into the section until it bubbled from the vent valve, closing the vent valve, pressurizing to a predetermined level, and closing the test valve. Leaks were recorded by the divers, and the bolts around them re-tightened. One diver worked at the console and the other at the pipe structure about six feet away.

Disassembly. The assembled structural sections were unbolted and stacked within the pipe framework. Nuts and bolts were placed in a container, and gaskets were hung on a wire hook.

Ideally a simulated diving task would inherently contain problem-solving elements. However, it was felt that the present task did not supply suitable information to determine diver mental function. Accordingly, prior to and following the operations on the pipe structure, one member of the dive team completed a set of written diving and sentence completion problems.

Diving problems. Three written problems requiring the calculation of pressures and volumes as a function of depth, or the use of the U.S. Navy Dive Tables to determine remaining bottom time, were presented during the pretest and posttest periods. Each problem had several parts. The diver was required to fill in blanks using mental reasoning alone or any available "scratchpads."

Sentence comprehension. A logic test previously used by Baddeley (1968) to examine the effects of nitrogen narcosis on per.formance at depth was administered in the present study. The test was comprised of short sentences describing the order of two

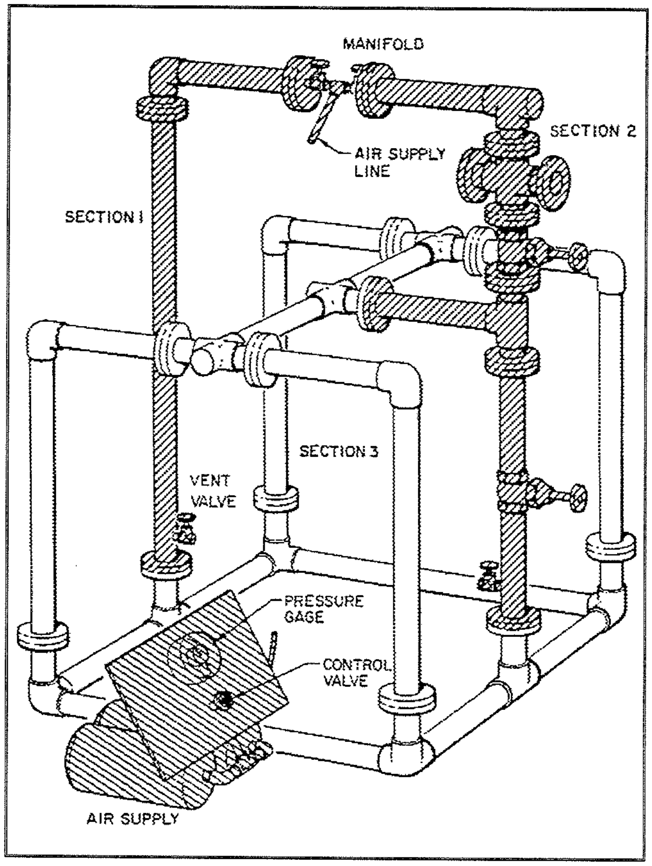

Figure 1.

following letters. The diver had to examine the sentence and the associated letters, and mark whether the sentence was true or false. For example:

		True	False
1. B precedes A	AB		✓
2. A follows B	BA	✓	
3. A does not precede B	BA	✓	

Twenty problems were presented before structure assembly and 20 after; the diver worked at his own pace. The diver working the problems was given one more job - log-keeping. He recorded on the instruction sheet the times at which the major activities described above were begun and ended.

Test Locales

Performance tests were conducted in a diving tank at a depth of 15 ft., and in the ocean at a depth of 18-20 ft. The diving tank formed part of the UCLA Underwater Research Facility, and was equipped with Plexiglas observation ports, electrical pass-through to an adjoining instrumentation room, and connections for hose-supplied SCUBA apparatus. Tank water temperature was about 80° F. The ocean test site was a flat sandy area adjacent to the Marineland of the Pacific pier at Palos Verdes, California. It had only moderate wave surge during the study period, and an average water temperature of 62° F at working depth.

Performance Data

The following types of performance data were obtained during the tank and ocean trials:

Task completion times. Completion time data were obtained following each run from the log kept by the divers, and were cross-checked by the observers and experimenters.

Problem accuracy. The problem sets were brought to the surface following each dive, and were immediately scored by the experimenter. If any part of a dive problem was in error, the whole problem was considered wrong.

Activity analysis. Analyses of diving activities during pipe structure assembly and during pressure testing were conducted by keeping a tally of observed diver actions at 15-sec. sample times. Activities were defined at the level of discrete, job-related events. For the assembly phase, the tallied items were:

1. Fit bolt or nut: Diver was inserting bolt or hand-tightening nut into a flange at joint.
2. Fit gasket: Diver was inserting gasket between flanges at joint.
3. Torque bolt: Diver was using torque wrench actively to tighten bolted connections.
4. Hold part or tool: Diver was holding part of assembly in place, holding bolt or nut, or passively holding crescent wrench on nut while partner tightened.
5. Transport part or tool: Diver was moving a unit from one location to another.
6. Travel empty: Diver was moving to or from a job but not carrying anything.
7. Communicate: Diver was attempting to exchange information with partner by hand or audio signals.
8. Read instructions: Diver was referring to diagram or written sheets.
9. Observe/idle: Diver was standing by motionlessly observing partner or assembly.

Later in the analysis, activities 1 and 2 were combined because they both required similar manipulative actions around the pipe joints and could overlap.

Several items were changed for the pressure-test analysis. The tallied activities for this task were:

1. Observe state: Diver was reading gauge, checking air flow, or monitoring pipe joint for leaks.
2. Control valve: Diver was manipulating valves in order to control air flow and raise or lower pressure in structure.
3. Service leak: Diver was adjusting hose connection, tightening bolt, etc., to correct minor air leakage problem.

Transport part or tool: Same as 5 above.
Travel empty: Same as 6 above.
Communicate: Same as 7 above.
Read instructions: Same as 8 above.
Observe/idle: Same as 9 above.

Christensen and Mills (1967) have suggested a classification of task activities into motor, perceptual, communication, and mediational processes. Our classification included examples of all but mediational activities, such as problem-solving and decision-making. These were excluded because we could not unequivocally determine when a diver was conducting such an activity. Thus he might well have been thinking actively when the observer marked him idle.

Previous experience had shown that an on-site observer could record up to nine activity classes on two-man teams without appreciable error (Weltman, *et al.*, 1968). In the present study, the observer sampled the activity of both members of the-diving team each 15 sec. recording his observations on a hand-held tally sheet. At the end of the dive, the entries in each activity class were totaled and recorded. It was assumed that the proportion of entries reflected linearly the proportion of dive time spent at that activity.

Physiological recording. Three physiological variables were recorded continuously during the dives; these were heart rate, respiratory rate, and inspiratory minute volume. The recording techniques have been previously described (Weltman, *et al.*, 1968). A new field-transportable recording unit was developed for this study. In brief, the diver-subjects breathed from a bottled compressed air supply (located on the surface) through a 135-psia "hookah" hose which terminated in a standard, single-hose demand regulator attached to a light harness. Inspiratory air flow to the subject diver was measured by means of a laminar flow element and associated differential pressure transducer placed in his air supply line. The flow signal was integrated over one-minute intervals to provide a sequential record of inspiratory minute volume. Electrocardiograph signals were recorded by means of waterproofed silver-silver chloride skin electrodes connected by a 100-ft. shielded cable to a high-input impedance preamplifier. Integrated inspiratory flow and the electrocardiogram were recorded on a strip chart recorder. Respiration rate was derived from the integrated signal by counting the "steps" for each minute interval.

Subjects

Five experienced male divers and 15 novice male divers participated in the study. The experienced divers were project personnel, ranging in age from 19 to 35 years, who had been diving consistently for at least two years, except for one subject, they were either diving instructors or members of the UCLA advanced diving program. The novices, who ranged in age from 19 to 25 years, were volunteers recruited from the current UCLA SCUBA diving class. Because of the stringent entrance requirements, all were strong swimmers. At the time they were tested in the present study, they had completed their rigorous pool training with tank and regulator, and an ocean checkout in wet suit only. The present ocean trials were their first with full SCUBA gear.

Experimental Design and Procedure

The experienced divers all received at least four training trials in the tank; half the novice divers received one training trial, and half received two trials. All divers practiced written problem solutions prior to their first tank trial. Previous study of a similar task showed that the greatest proportion of learning occurred between the first and second trial (Weltman, *et al.*, 1968). Both groups were run first in the tank and then in the ocean; thus any further learning worked against the demonstration of an adverse ocean effect, which had been hypothesized.

The five experienced divers were paired in all possible combinations to form ten distinct teams. Team performance on the task simulation was examined once in the tank and once in the ocean, so that each experienced diver participated four times in each environment in a random order of exposure. Problems of scheduling and subject availability precluded such a balanced arrangement for the novices. Instead, 12 subjects formed nine teams for the tank runs (individuals participated once or twice), and seven subjects formed five different teams for the ocean runs. Neither novice nor experienced divers ran twice with the same partner in tank or ocean. Nonparametric methods were used throughout the statistical analyses. Paired comparisons (sign test or Wilcoxon signed-ranks test) were used to analyze differences in experienced team performance due to environmental conditions; the less powerful Mann-Whitney *U* test served the same function for the novice teams, and for comparisons between the novice and experienced groups. Intraenvironmental comparisons for both groups were generally able to employ the signed-rank test.

Before a run, the diving team was given time to discuss their approach to the task and their modes of communication. One diver was attached to the physiological recording system. (Every experienced diver was instrumented twice in each environment. Physiological data were obtained for 10 of the 12 novice participants in the tank trials, and for all seven participants in the ocean trials.) After entering the water, the instrumented diver completed the pretest problems while his partner stood by. Both divers assembled, pressure-tested, and disassembled the structure. The instrumented diver then completed the posttest problems, and the team surfaced. No subject saw exactly the same pretest or posttest problems twice. Team activity was scored by an experimenter looking through a viewport in the tank runs, and by a diver-observer in the ocean. For the tank runs, the subjects wore wet-suit hoods and jackets in addition to their masks and fins in order to inhibit their movements somewhat and provide better comparison with the subsequent ocean exposures in full wet suits. They reported no discomfort in the tank due to warmth.

RESULTS

General Performance

A major aim of the simulated task was to impose the necessity for teamwork on the diver subjects. It appeared that this aim was met, at least during the assembly and pressure test phases. The awkward shapes and weights of the flanged pipe components forced the divers to work as a team if assembly was to be accomplished in a timely manner. During pressure testing, the divers communicated with each other by prearranged visual gestures and auditory signals. If leaks were detected during the tests, both divers usually attempted to remedy the situation as a team activity.

Disassembly was performed more independently, with each diver usually loosening different flanges and replacing the pipe components on the structure base. Few major errors were connected with work on the pipe structure either in the tank or ocean, probably because the task was well practiced. The errors which did occur were mainly misplacement of solid for open gaskets, and failure to tighten bolts adequately.

Task Completion Time

Table 1 summarizes observed completion times for the various parts of the simulated task, with the pipe-structure operations separated from those involving the problem sets. For the pipe structure portion, the experienced teams showed little change between tank and ocean environments in the time required to complete all three task elements. Only the 13% increase in assembly time approached statistical significance ($p = .06$). The novice teams, on the other hand, showed marked differences between the two environments. Total completion time increased 26% in the ocean ($p = .0\ 1$), while both the assembly and disassembly sub-tasks showed 36% decrements ($p = .05$ in each case). Novices demonstrated significantly longer total completion times than the experienced divers both in the tank ($p = .002$) and in the ocean ($p = .001$). Although experienced and novice teams showed a mean decrease in pressure test times between tank and ocean, the differences were not significant in either case.

Since the ten experienced teams were comprised of only five subjects, it was of interest to see whether particular divers or diver combinations consistently contributed fast or slow performance times. Means were computed for the four runs participated in by each diver in both environments. These ranged from 21.0 to 25.9 min. in the tank, and from 21.0 to 24.9 min. in the ocean, a difference of only about +/- 12% from the overall mean. There was no significant correlation between mean completion times in the tank and in the ocean (Spearman rank-correlation coefficient $r_S = .10$). A Spearman rank-correlation analysis between tank and ocean times was also conducted for the ten teams. The coefficient was slightly higher ($r_S = .35$) but still not significant. It appeared that the members of the experienced group and the teams they formed had about equal capabilities for diving work.

The values given in Table 1 for problem sets represent the time required by the average diver to complete both the diving questions and the logic problems. Neither the experienced nor the novice groups showed significant differences between pretest and posttest problem solution time in either environment, nor were the novices' times significantly different from those of the experienced divers. Mean problem set completion times were lower in the ocean, but the differences between the tank and ocean were not significant for pretest, posttest, or total times in either group. However, considering the times for pressure testing along with those for problem solution, it seemed that in the ocean the divers tended to hurry any tasks requiring deliberation, in contrast to their slower performance of the relatively incompressible mechanical sequences.

Task	*Experienced Diver Teams*		*Novice Diver Teams*	
	Tank N=10	*Ocean N=10*	*Tank N=9*	*Ocean N=5*
Pipe Structure				
Assembly	12.3	13.9	19.3	26.2
Pressure-Test	4.7	3.6	7.5	6.6
Disassembly	5.4	5.6	9.1	12.4
Total	22.4	23.1	35.9	45.2
Problem Sets				
Pretest	5.6	4.2	6.9	4.8
Posttest	5.5	4.4	6.3	4.4
Total	11.1	8.6	13.2	9.2

Table 1. Summary of Mean Task Completion Times (Minutes)

Problem Solving

Table 2 summarizes problem-solving performance for the two groups of subjects. Sentence comprehension showed no consistent change with environment or exposure; novice and experienced divers performed at relatively high levels in tank and ocean, before and after work on the pipe structure.

Mean performance in the present study (93.5 %) was almost the same as that reported by Baddeley, *et al.* (1968) (94.2%) for similar shallow water test conditions.

On the other hand, responses to the diving questions, which required a greater degree of factual recall and "free" reasoning, were apparently adversely affected by ocean exposure. For the experienced divers, there was no significant difference between pretest and posttest problem-solving in either environment, but performance fell appreciably in the ocean. Considering pretest and posttest scores together, four of the five subjects performed more poorly in the ocean than in the tank. The novices' scores reached about the same level as the experienced divers' in the tank pretest, but apparently deteriorated both as a function of exposure and environment. For the novices in the tank, the decrease between pretest and posttest trials was significant ($p = .035$). The largest ocean effect for the novices was shown between tank and ocean pretest scores. The observed difference in these scores was significant ($p = 0.05$) when tested by the exact probabilities test for independent samples, despite the fact that some ocean subjects had had extra practice with the problems in the tank. Thus it appeared that the adverse effect of the ocean at the beginning of a dive overcome any practice effect for novices.

In the ocean, the novices mean problem-solving performance did not fall below the pretest level even after an average exposure of 50 minutes, although the posttest level was slightly lower than in the equivalent tank trials. One might hypothesize that two sets of influential factors were at work on the novice divers. That is, initial anxiety may have lowered the pretest scores, and as anxiety wore off somewhat with time, the effects of cold and exhaustion might have continued to degrade performance. If this hypothesis were valid, we would expect the experienced divers, who were probably not affected by anxiety at the shallow test depth, to show some adverse effects of cold etc., in the ocean posttest. There was, in fact, a tendency in this direction, although the change was understandably slight, since the average experienced diver spent only about 27 min. under water before his posttest, in contrast to 43 minutes for the novice subject.

Test	*Experienced Diver*	*Teams*	*Novice Diver*	*Teams*
	Tank (N=5)	*Ocean (N=5)*	*Tank (N=10)*	*Ocean (N=7)*
Dive Questions				
Pretest	90	83	87	52
Posttest	93	77	60	57
Sentence Comprehension				
Pretest	91	97	91	92
Posttest	96	97	93	90

Table 2. Summary of Problem-Solving Performance (Percent Correct)

Activity	*Experienced Diver*	*Teams*	*Novice Diver*	*Teams*
	Tank N=5	*Ocean N=5*	*Tank N=12*	*Ocean N=6*
Fit bolt, nut, gasket	31.7	37.5	30.4	35.9
Hold part or tool	26.5	23.6	26.8	21.3
Torque bolt	20.6	21.3	17.1	21.8
Move part or tool	13.2	12.5	13.2	9.9
Communicate	1.0	0.6	3.6	4.1
Read instructions	0.5	0.0	1.0	0.0
Idle/observe	1.0	1.2	4.0	4.1
Travel empty	5.5	3.3	3.9	2.9
Total Percent	100.0	100.0	100.0	100.0
(Total Number of Tallies)	(1,795)	(1,850)	(882)	(587)

Table 3. Activity Analysis for Pipe Structure Assembly (Percent).

Activity	*Experienced Diver*	*Teams*	*Novice Diver*	*Teams*
	Tank N=5	*Ocean N=5*	*Tank N=12*	*Ocean N=6*
Valve control	37.3	47.7	22.4	36.1
Observe condition	17.5	21.5	13.5	20.6
Move part or tool	1.4	6.7	1.7	7.2
Communicate	13.7	2.6	9.5	1.0
Read instructions	10.0	10.2	23.0	17.5
Idle/observe	14.9	6.1	16.6	4.2
Travel empty	3.3	2.6	3.1	3.1
Correct error	1.9	2.6	10.2	10.3
Total Percent	100.0	100.0	100.0	100.0
(Total Number of Tallies)	(752)	(576)	(295)	(97)

Table 4. Activity Analysis for Pipe Structure Pressure Test (Percent).

Activity Analysis

Tables 3 and 4 summarize the activity analysis for the pipe structure assembly and pressure test operations, respectively. The assembly analysis is probably a more reliable medium for comparisons between groups and environments because it is based on a lengthier task, and consequently on more sample points. The assembly data revealed that there were no gross differences between novice and experienced divers in the way the task was accomplished in tank and ocean, at least with respect to the main motor activities. Roughly 50% of the diver's time was spent fitting and tightening nuts and bolts, and a total of 90% was spent in motor activities directly related to mechanically rigging the pipe structure (first four categories).

Some consistent differences between groups appeared in what might be termed subsidiary and nonproductive categories (last four categories). Novices spent about 4% of their time communicating and checking the instructions in both environments; experienced divers devoted only about 1% of their time to these activities. Idle observation occupied 4% of the novices' time, but only 1% of the experienced divers'. Both diver groups showed a slight reduction from tank to ocean in the total amount of time spent nonproductively, the experienced divers from 12.5 to 10%, the novices from 7.9 to 6.0%. One might anticipate from previous studies that the colder ocean environment would have specifically degraded manipulative activities such as bolt-fitting and wrench-handling. There was some indication of this. Both novice and experienced divers showed roughly a 6% increase in the time spent fitting bolts, nuts, and gaskets, and a small but consistent increase in time spent torquing.

In contrast to the assembly results, there were some substantial shifts in the mean activity profiles for pressure testing as the divers moved from tank to ocean. For the experienced group, the proportion of time spent in communication and checking procedures fell from 25 to 13%, that spent in nonproductive observation and travel fell from 20 to 11%. Consequently, the time spent directly in control processes rose from 55 to 70%. The trend was similar for the novice group. Communication and checking procedures decreased from 33 to 19%, observation and travel activities decreased from 30 to 18%, and control processes increased from 36 to 57%.

Thus both diver groups apparently conducted pressure testing more efficiently in the ocean. This was reflected also in their lower task completion times (Table 1). The change may have been due to additional learning; although for the experienced divers at least, the tank trials should have provided ample practice. More likely, observed changes were part of the general tendency to act less deliberately whenever possible in the ocean. This has been previously noted as the most likely basis for lowered problem solution times. For example, the major differences between the experienced and novice divers in the pressure-testing task was during the tank trials, when the novice spent considerably more time studying the instructions. In the ocean, profiles for the two groups were much the same, as were their completion times. The results suggest that diving experience influences gross mechanical tasks involving manipulation and skilled movement, such as the assembly task, more than it does sedentary tasks involving team coordination and simple control processes.

Physiological Response

The physiological data are summarized in Table 5; each tabled entry represents the mean for the subject group of rates calculated at two-minute intervals during the particular task phase. Heart rate and respiration rate are presented in beats per minute and breaths per minute, respectively. Inspiratory minute volume is presented in terms of surface-equivalent ventilation in cubic feet per minute, rather than in terms of the actual mass of air consumed at depth. Therefore, 1 cu-ft/min breathed at 33 ft. involves the same chest ventilation as 1 cu-ft/min breathed on the surface, although at depth, twice as much gas is removed from the storage supply.

Previous examination in the tank of a similar pipe-structure task (Weltman and Egstrom, 1969) revealed that the assembly operation imposed only a mild physiological load, approximately equivalent to surface bicycle exercise at 500 kg-m/min. The 14-man subject group in that study showed a mean heart rate of 98 beats/min., and a mean inspiratory minute volume of .81 cu-ft/min. The present results evidenced the same low load for the assembly portion. Both novice and experienced divers had mean heart rates and inspiratory minute volumes in the vicinity of the previous findings under equivalent work conditions. On the basis of the tank data, it appeared that the present disassembly operation involved slightly less exertion than assembly, and that the largely static problem-solving and pressure test operations were very close to underwater rest.

In the tank, the levels of heart rate response over the various task phases were quite similar for the experienced and novice divers, although respiratory patterns differed for the two groups. The novices breathed faster and showed somewhat higher inspiratory minute volume levels than the experienced divers. Since "skip breathing" and air conservation is an acquired habit with SCUBA divers, the novices' responses did not necessarfly reflect any physiological discomfort or work disadvantage in the tank situation. In the ocean, the heart rate levels of the experienced divers rose slightly during the less strenuous portions of the task, while the respiratory responses remained generally the same. The novice response pattern, on the other hand, changed radically; heart rate, inspiratory minute volume, and respiration rate all increased, in no apparent relation to task difficulty. Figure 2 shows this trend more clearly for the heart rate variable. The novice ocean runs began (pretest) with elevated heart rate levels; heart rate gradually "settled out" until near the end of the run the response appeared again related to workload, but the final level was still well above the corresponding tank values. (The plots for inspiratory minute volume and respiration rate looked much the same.) Some of the novices who were instrumented in both tank and ocean showed heart rate increments of more than 60 beats in the ocean for the pretest period.

Could the new response pattern have been due to environmental changes in the ocean, *i.e.*, cold, reduced visibility, surge, etc.? Several factors argue against cold as an effect. First, one would not expect cold to act differently on experienced and inexperienced divers. Second, cold effects would seemingly worsen with time, not lessen; and finally, cold-induced peripheral vasoconstriction should decrease heart rate by acting to raise blood pressure. Previous reports of exposure to colder water have indicated that heart rate does slow (Bowen, 1968. Weltman, *et al,* 1968), but not during the sedentary task portions. The same comment holds for the effect of moderate surge and slightly reduced visibility. The most likely explanation is that the observed heart rate increase and overbreathing were the result of

Task Phase	Experienced Divers Tank N=5 HR[1]	MV[2]	RR[3]	Ocean N=5 HR	MV	RR	Novice Divers Tank N=10 HR	MV	RR	Ocean N=7 HR	MV	RR
Pretest												
Problems	75	.54	7	85	.60	9	80	.65	12	116	1.08	19
Assembly	90	.77	9	95	.70	9	92	.94	14	103	.75	14
Pressure-test	82	.72	8	92	.70	9	81	.77	13	97	.76	15
Disassembly	90	.68	9	97	.80	10	85	.83	14	98	.88	17
Posttest												
Problems	73	.65	8	78	.58	8	77	.72	13	95	.75	16
Mean	83	.67	8.2	90	.68	9	83	.78	13.2	102	.84	16.2

[1] Heart rate (beats/min).
[2] Inspiratory minute volume (ft^3/min).
[3] Respiration rate (breaths/min).

Table 5. Summary of Physiological Data.

heightened anxiety and/or arousal in the ocean, that the psychological factor affected the novices more than the experienced divers, and that the greatest effect on the novices occurred as they entered the water. These conclusions are certainly not at odds with other observations of inexperienced divers in the open ocean (Weltman and Egstrom, 1966), or with the known relationship of anxiety to physiological measures (*e.g.*, Pitts, 1968).

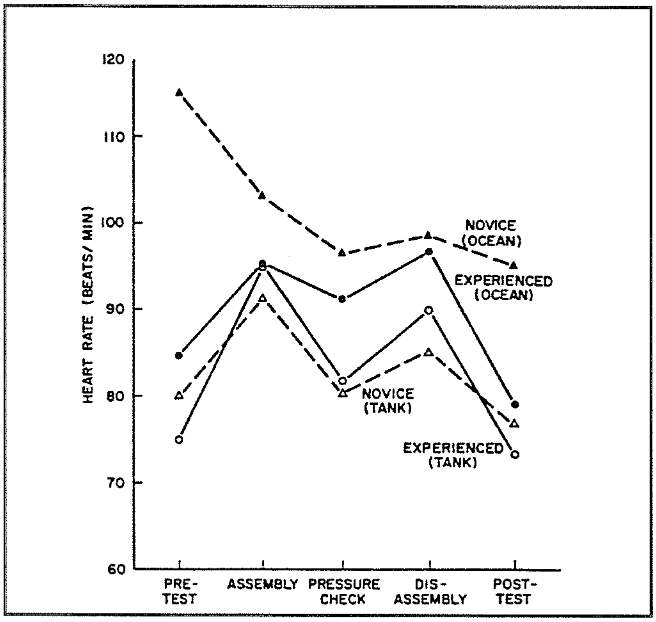

Figure 2. Mean Heart Rate Values for Novice and Experienced diver groups during tank and ocean trials.

It is interesting that for the novice divers, psychological stress acted to raise the heart rate baseline so that the normally wide swings between inactive and active states were flattened. For the experienced divers, on the other hand, the ocean increment was added more uniformly to the various task phases, so that the size of the swings was nearly the same as in the tank. Perhaps the difference was between anxiety in the novices and arousal in the experienced divers, if such a fine distinction can be made in the present situation. Alternatively, perhaps the increase in response levels for the experienced group actually reflected a small additional workload imposed by the new environment. Present evidence is insufficient to permit a decision between these alternatives.

CONCLUSIONS

The present study involved three identifiable negative influences on complex underwater work performance: inexperience in diving, working in the ocean rather than in a tank, and situational anxiety. Although the experimental design was not one to permit unequivocal separation of these effects and their associated interactions, the findings do help to gauge their relative importance. In the tank, where anxiety was assumed minimal, diving inexperience increased total work time on the pipe construction task (assembly, pressure-test, disassembly) by 60%, and had no apparent effect on total problem-solving time. For the experienced divers, working in the ocean raised total construction task time only 3%. This closely matches the 4% average decrement in psychomotor task performance reported by Bowen (1968) for the transition from 72- to 62°-F water. It seems reasonable to assume that for the experienced divers, any ocean effect on construction task performance was due to environmental factors. On the other hand, the experienced divers showed an appreciable drop in the percentage of dive problems entirely correct in the ocean. The decrement seemed greater than that reported by Bowen for mental function in cold water, and might possibly be due to psychological arousal in the ocean situation.

The novice teams were 60% slower on the total construction task than the experienced teams in the tank, and working in the ocean slowed the novice tank times by an additional 26%. Simultaneous measurements of heart rate and respiration rate indicated the novice group was under psychological stress, particularly at the beginning of each run. Baddeley (1967) has estimated the adverse effect of anxiety alone on psychomotor performance as about 4.3% (screwplate test performed prior to dive). Accepting this estimate, we might conclude that the detrimental effect of the ocean environment for inexperienced divers is nearer 20% than 3%. Alternatively, Baddeley (1967) and Weltman and Egstrom (1966) have both hypothesized that anxiety may have a more marked effect underwater than on the surface. In that case, the increase in novice performance time due to anxiety may have been more like 23%, the figure obtained by assuming the environmental effect was the same for both groups. The degradation in dive problem accuracy during their ocean pretest suggests that, for novices, the psychological factor is more important than Baddeley's surface data indicate, and even at shallow depths about a 20% decrement is a reasonable estimate.

Except for small extra percentages of time spent in less productive activities such as communications, idle observation, unloaded travel, error correction, etc., the novice divers accomplished the assembly and pressure-test tasks with much the same activity profiles as the experienced divers, both in the tank and in the ocean. Thus the main apparent advantage of diving experience was the ability to deal with the novel physical factors in the environment (lack of traction, restriction of vision, free body positioning, etc.) rather than the ability to find job shortcuts. Novice and experienced divers alike seemed to perform less deliberately during ocean problem-solving and pressure-test procedures. Perhaps the uncomfortable environment promoted the urge to "hurry and get it over with" where job requirements did not interfere. Bowen (1968) has reported a similar speed-up in cold-water problem-solving.

Relating the present findings to the future study of underwater work, we would conclude that for well-defined complex tasks of moderate workload, the use of experienced divers in a cooled tank will provide a close approximation to actual ocean operations at nominal depths. Baddeley, *et. al.* (1968) recently reported similar absence of unique "ocean impairment" in a study of nitrogen narcosis conducted in a dry pressure chamber and at 100 ft. under ideal ocean conditions.

This does not imply that tank simulations can substitute entirely for ocean trials, but only that a good deal of reliable biotechnical data may be available through the less costly approach. The limits to tank simulation are evidently determined by those combinations of adverse ocean conditions (depth, visibility, danger, etc.) which produce appreciable psychological effects in experienced divers. These "boundaries" are certainly not well-defined at present; nevertheless, previous reports indicate their existence (Baddeley, 1966; Bowen, *et al.*, 1966) and their possible dependence on individual characteristics (Weltman and Egstrom, 1966). They should be the subject of further research, particularly in the area of problem-solving and judgment, which emerged as highly sensitive in the present study. In this respect, careful thought will have to be given to experimental designs which permit delineation of the various stresses of deep ocean diving.

The present findings discourage the use of inexperienced subjects in examination of complex underwater performance, except for the unlikely objective of predicting the performance of other inexperienced divers. Our data indicated that the diving skills developed by experience had a significant effect even on a relatively simple task performed in a tank. In the ocean, the difference between experienced and inexperienced performance was substantial, and probably contained a major psychological component. Consistent use of experienced divers is the best approach evaluating ocean diving performance.

Of course, the precise definition of "experienced diver" is not without problems. The present study compared rank novices to experienced sports divers in shallow water. At depths of several hundred feet, under truly adverse conditions, many of our experienced group would occupy nearly the same relative position as the novices. It would seem that at the least, in addition to being thoroughly familiar with the gear involved, the experienced man is one who dives regularly to respectable ocean depths for the purpose of accomplishing underwater work. Any group undertaking realistic studies of underwater performance, task design, equipment use, etc., appears obligated to train or otherwise acquire the services of such divers.

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